SOME FLUCTUATIONS IN THE JET STREAM AND TROPOPAUSE ASSOCIATED WITH CYCLONIC DEVELOPMENT AND MOVEMENT, FEBRUARY 18-21, 1954

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INTRODUCTION

The purpose of this paper is to study the behavior of the jet stream and the tropopause associated with a deep moving cyclone, and especially to study carefully irregularities in winds aloft and temperature reports that do not seem to conform logically to currently envisioned models of jet stream mechanisms and analysis. The emphasis of the paper thus is on such problems as are encountered in day-to-day analysis operations. One of the more widely accepted notions is inferred from the thermal wind equation; that is, winds should increase with height so long as there is a horizontal temperature gradient with colder air to the left of the observed winds. Thus, in a simple idealized case, over the leading edge of a deep cold dome one would expect the wind speeds to increase with height up to the tropopause where the temperature gradient suddenly reverses. Such a case will be described here.

The storm chosen for this study developed in central Wyoming at 1830 GMT, February 18, 1954 along a cold frontal boundary between cold, maritime air to the northwest and warm, highly modified, continental air to the southeast. This storm moved southeastward into Kansas and then recurved to the northeast, passing just to the west of Lake Michigan. With the track of the surface Low center passing through the central part of the United States, the associated jet stream also remained within the States, providing sufficient data for accurate analyses of conditions aloft. This storm will be studied primarily along a fixed cross-section.

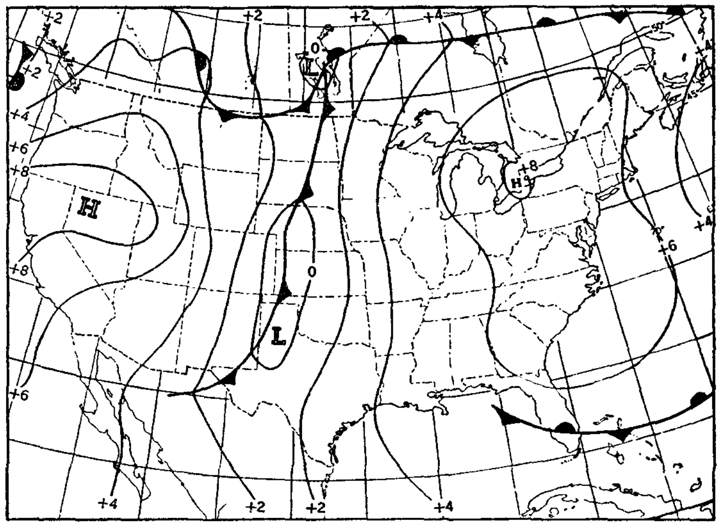

FIGURE 1.—1,000-mb. chart at 0300 GMT on February 19, 1954. Contours are in hundreds of geopotential feet.

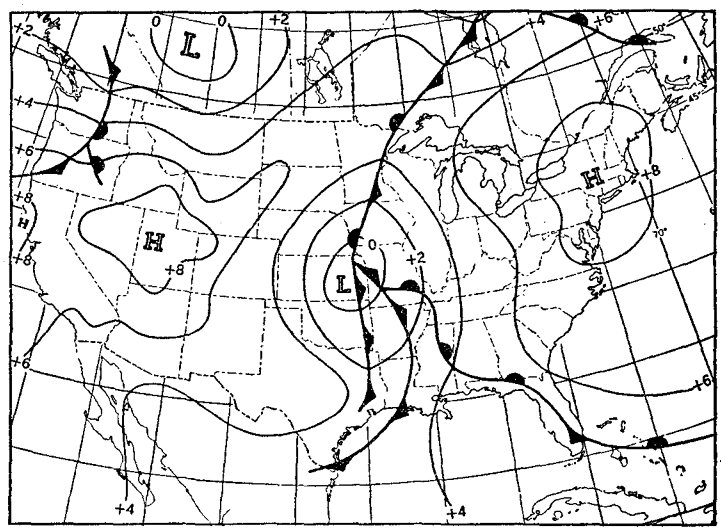

FIGURE 2.—1,000-mb. chart at 0300 GMT on February 20, 1954.

SURFACE SYNOPTIC CONDITIONS

At 1830 GMT, February 18, 1954 a cold front extended south-southwestward from a 992-mb. Low located in southern Saskatchewan. This front was the leading edge of a well-defined surge of maritime polar air which moved eastward into the United States from the Pacific and contributed to the formatión of a strong Basin High. Some idea of the intensity of this cold front was indicated by the fact that the thermal wind gradient in the 1000–500-mb. layer averaged about 50 knots behind the front. Also, on the corresponding 700-mb. chart the −15° C.

isotherm dipped down to Elko, Nev., behind the front, and ahead of the front the −5° C. isotherm reached as far north as The Pas, Manitoba.

At 1830 GMT, February 18, the storm of interest in this study first appeared as a 996-mb. Low in central Wyoming. Thus, this storm began as a secondary development along and in association with the cold front extending southward from its parent Low in Canada. This secondary Low moved southeastward from Wyoming and at 0300 GMT, February 19 (fig. 1), was located in western Kansas with a central sea level pressure of 994 mb. Twenty-four hours later (fig. 2) the Low center had moved into the northeastern corner of Kansas, and the central pressure had changed very little. However, the storm had greatly intensified and at this time had become a primary center. As seen from figure 2 the intensification resulted from the building of a ridge line across the front to the north of this Low center.

By 1500 GMT, February 19, a secondary cold front had formed in the cold air (this may be followed in the cross-sections shown in figures 9–12). The warm front over Florida had become more pronounced by 0300 GMT, February 20, and was associated with the main storm, intersecting the cold front in southern Missouri. West of the Appalachians this warm front moved rapidly northward and by 0300 GMT, February 21 (fig. 3), was just north of Buffalo. The Low center was located in northern Wisconsin with a pressure of 993 mb.

JET STREAM

The 200-mb. trough associated with this surface Low may be seen in figures 4–6. It may also be noted that the jet stream entering the west coast near latitude 40° N. curved south of the surface position of the Low. This relationship between the jet stream and extratropical cyclones has been found favorable for the deepening of storms [1]. Although this storm did not deepen, the

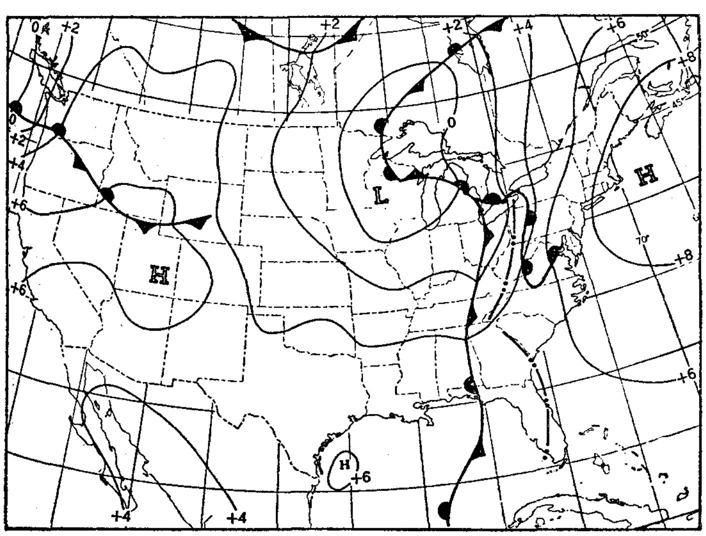

FIGURE 3.—1,000-mb. chart at 0300 GMT on February 21, 1954.

intensity, as measured by the pressure gradient around it, did increase very markedly. With regard to an example by Alaka, Jordan, and Renard [2] it was stated that a deepening Low is generally associated with a well, defined jet maximum and that throughout the period of intensification the Low is located to the left and forward of the jet maximum. In figures 5 and 6 the surface Low is found to the left and slightly behind the jet maximum. This might have been taken as an indication that the Low would not deepen any further.

Jet stream analysis can often become a problem when viewing constant pressure surfaces only. To avoid this difficulty, cross-sections were constructed along the same baseline for every 12 hours that the storm was in the United States. Six of these are reproduced in figures 7 through 12. Figures 8, 10, and 12 are synoptic with figures 4, 5, and 6.

The jet axis near Las Vegas, Nev., in figure 7, seemed to conform very well to the usual model; i. e., its axis sloped poleward with height below the 500-mb. level, remained almost vertical to the level of strongest winds, just below the tropopause, and sloped equatorward above that.

The jet maximum was very close to the 200-mb. level, while in the returning flow near Denver it was at a lower elevation. The axes of both flows appeared to be nearly vertical above the 500-mb. level. Twelve hours later (fig. 8) the northwesterly jet had the same slope, but the northwesterly winds had decreased while the southerlies had increased. Both axes were still nearly vertical above the 500-mb. level and both maxima were near 230 mb. However, by 1500 GMT, February 19 (fig. 9), the cross-section of the northwesterly jet had changed considerably. Below the 250-mb. level the axis had continued to move to the northeast and had weakened still further, but above the 250-mb. level the wind maximum still existed near Las Vegas, Nev. A maximum wind of 131 knots (normal to the cross-section) at the station was reported about two thousand feet *above* the tropopause, 22 knots greater than the reported wind at the tropopause. In view of the existing temperature field this report seemed highly unreliable. As a matter of fact the coexistence of such a wind and temperature field is a virtual impossibility, and for this reason the report was discarded as being erroneous. This was the only case in the series where the wind maximum was reported above the tropopause. With this wind discarded the jet followed a logical continuity, both in time and space, which is one of the fundamental principles of good analysis.

At this time, however, the northwesterly jet axis no longer retained a vertical slope above the 500-mb. level. The maximum wind was at Grand Junction, Colo., at 500 mb.; about half-way between Milford, Utah, and Grand Junction at 300 mb.; and northeast of Las Vegas at 200 mb. An inspection of the isotach charts at the three levels breaks down this seemingly single jet stream into two.

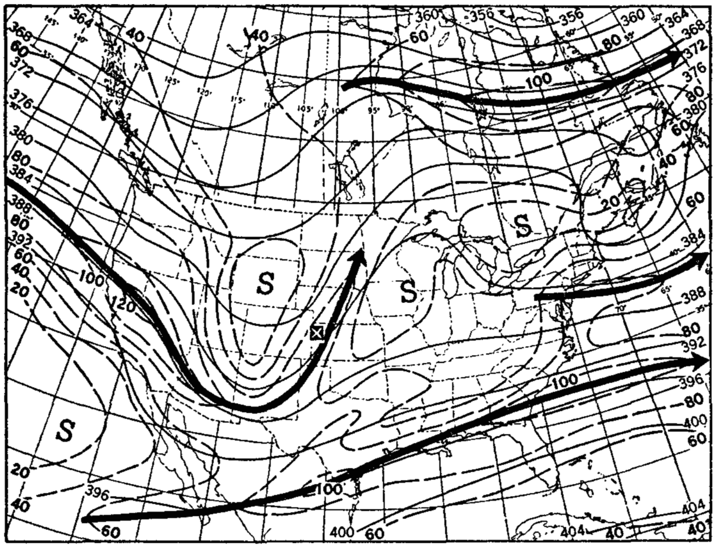

FIGURE 4.—200-mb. chart at 0300 GMT on February 19, 1954. Contours, continuous lines, are in hundreds of geopotential feet. The jet streams are indicated by the wide black lines with arrow heads. Isotachs, dashed lines, are in knots. For clarity the isotherms have been omitted. The small "x" denotes the surface Low center.

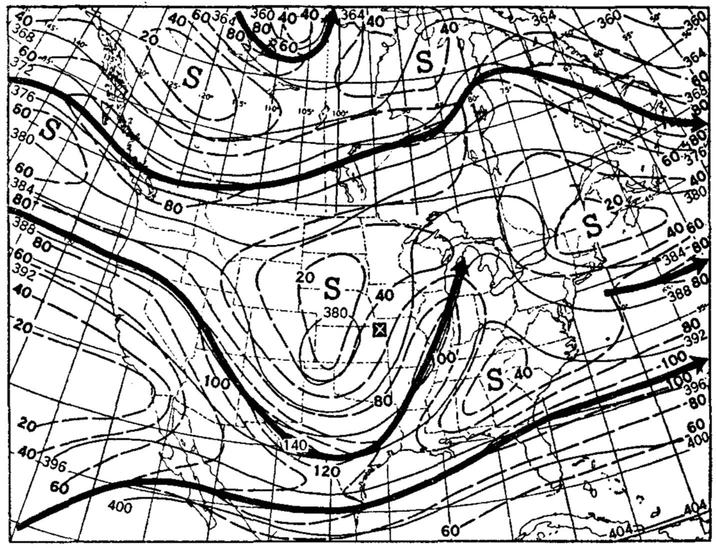

FIGURE 5.—200-mb. chart at 0300 GMT on February 20, 1954.

The lower one, in evidence on the 500-mb. and 300-mb. charts, entered the west coast near latitude 45° N., crossed southern Idaho, and then turned southward across eastern Utah to El Paso, Tex. This was the weaker of the two where it crossed the cross-section. The main jet stream, or core, was the one shown in figure 9 at about 200 mb. near Las Vegas. This is the one carried on the 200-mb. charts in figure, 4–6, and seems to be the main jet.

Figure 10, 0300 GMT, February 20, 12 hours later, shows this double jet a little more clearly. The lower level jet axis sloped from Denver at 500 mb. to a maximum near 300 mb. at Grand Junction. Associated with the main jet, which had a maximum near Milford at 200 mb., was a nearly vertical axis near Las Vegas. After another 12 hours (fig. 11) the maximum wind of the lower jet had increased to 100 knots, and both axes of the northwesterly jets were still very much in evidence. The relationship between the two jets was still the same as when they were first noticed in figure 9, but the maximum wind by this time had lowered to 300 mb. and was associated with the lower jet. The wind data for 400 and 500 mb. reported from Denver at this time seemed to be erroneous. After comparing them with the winds reported at 0900 and 2100 GMT and with the constant pressure charts for 1500 GMT, estimates of the true values were made and incorporated into the cross-section. By 0300 GMT, February 21 (fig. 12) the northwesterly flow normal to the cross-section had become rather flat and diffuse, but the two axes were still identifiable. One reason for this apparent flatness and diffuseness was the angle made by the cross-section surface through the flow pattern. At this time the cross-section cut through the northwesterly jet at a rather oblique angle thereby spreading the isotachs. In viewing all the cross-sections this relative orientation should be kept in mind.

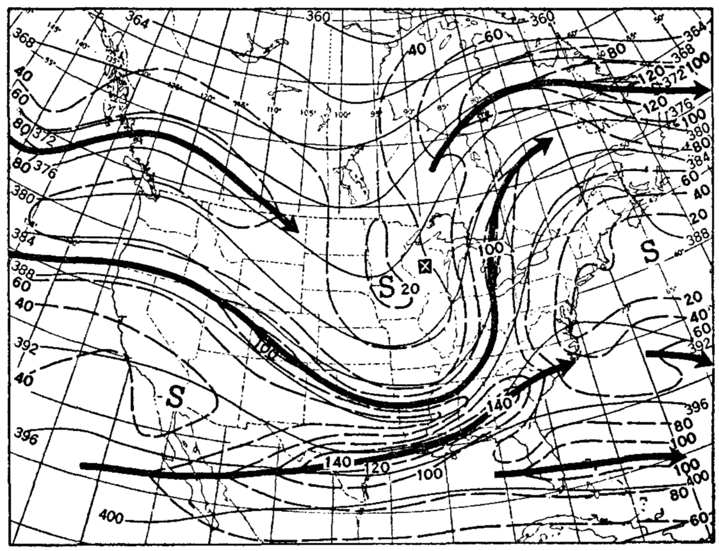

FIGURE 6.—200-mb. chart at 0300 GMT on February 21, 1954.

In the series of cross-sections the returning flow from the south steadily increased while that from the north decreased. This emphasizes the migration of the jet maximum around the trough line, as shown on the 200-mb. charts. In figure 4 the jet maximum is near Reno, Nev.; in figure 5 (24 hours later) it is between El Paso and Del Rio, Tex., and in figure 6 it is near Lake Superior. The axis of southerly flow remained nearly vertical throughout the series. The small wind maximum near 12,000 feet at Dayton, Ohio (fig. 12), might be attributed to gusts caused by instability, since thunderstorm activity was reported in the area at the tine.

The 200-mb. flow at 0300 GMT, February 21 (fig. 6) was marked by the rather sudden appearance of a jet over southern Florida. Although the geostrophic winds do not support such strong winds, the existence of this jet was borne out by the observed winds. The use of inter-

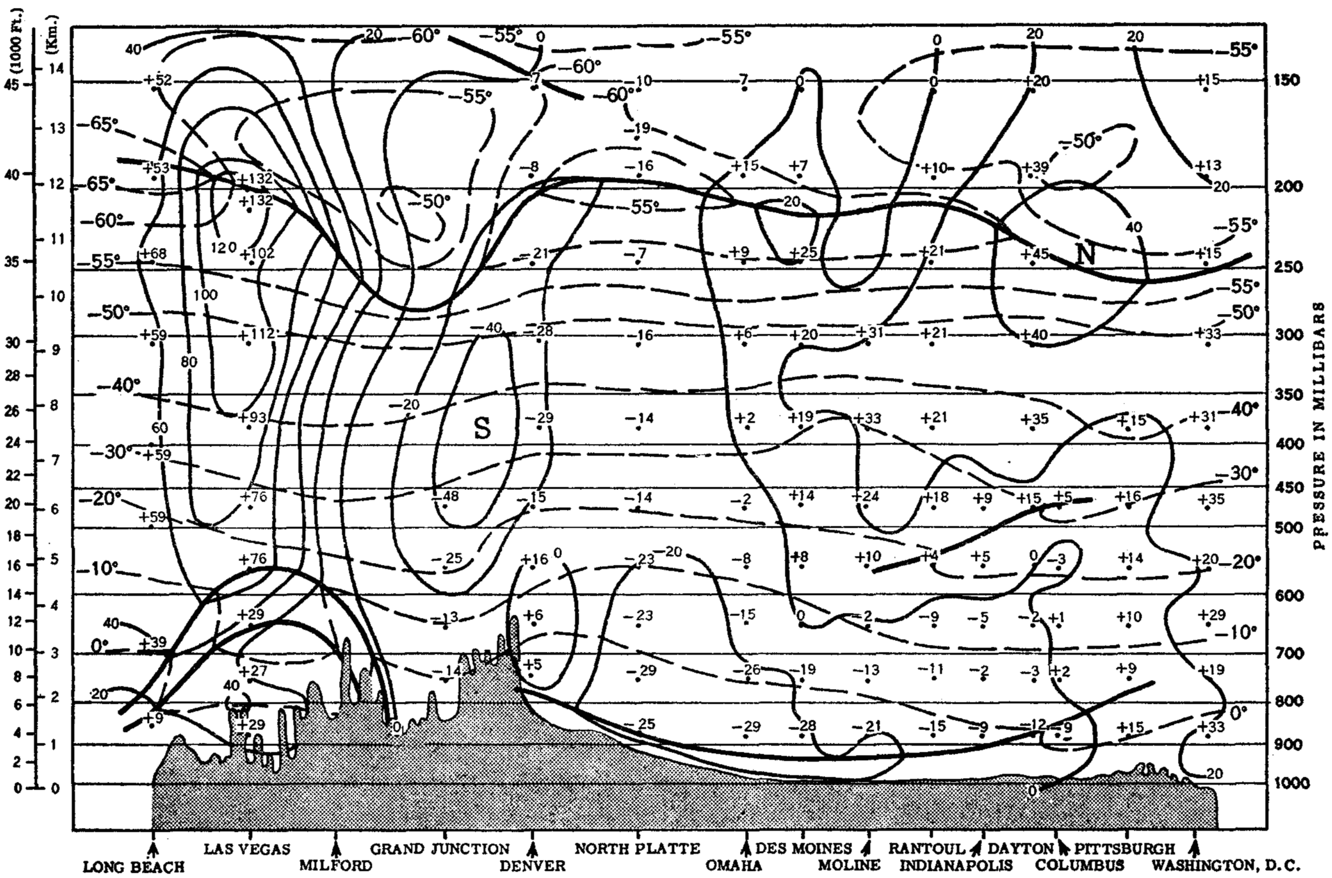

FIGURE 7.—Cross-section, roughly west-east, at 1500 GMT on February 18, 1954. Heavy lines indicate fronts, frontal zones, inversions, and tropopauses. Isotherms in ° C. are shown as dashed lines. Isotachs, shown as thin solid lines, give components of wind (knots) normal to cross-section; positive values are winds blowing out of the diagrams (i. e. from the north) and negative into the diagram.

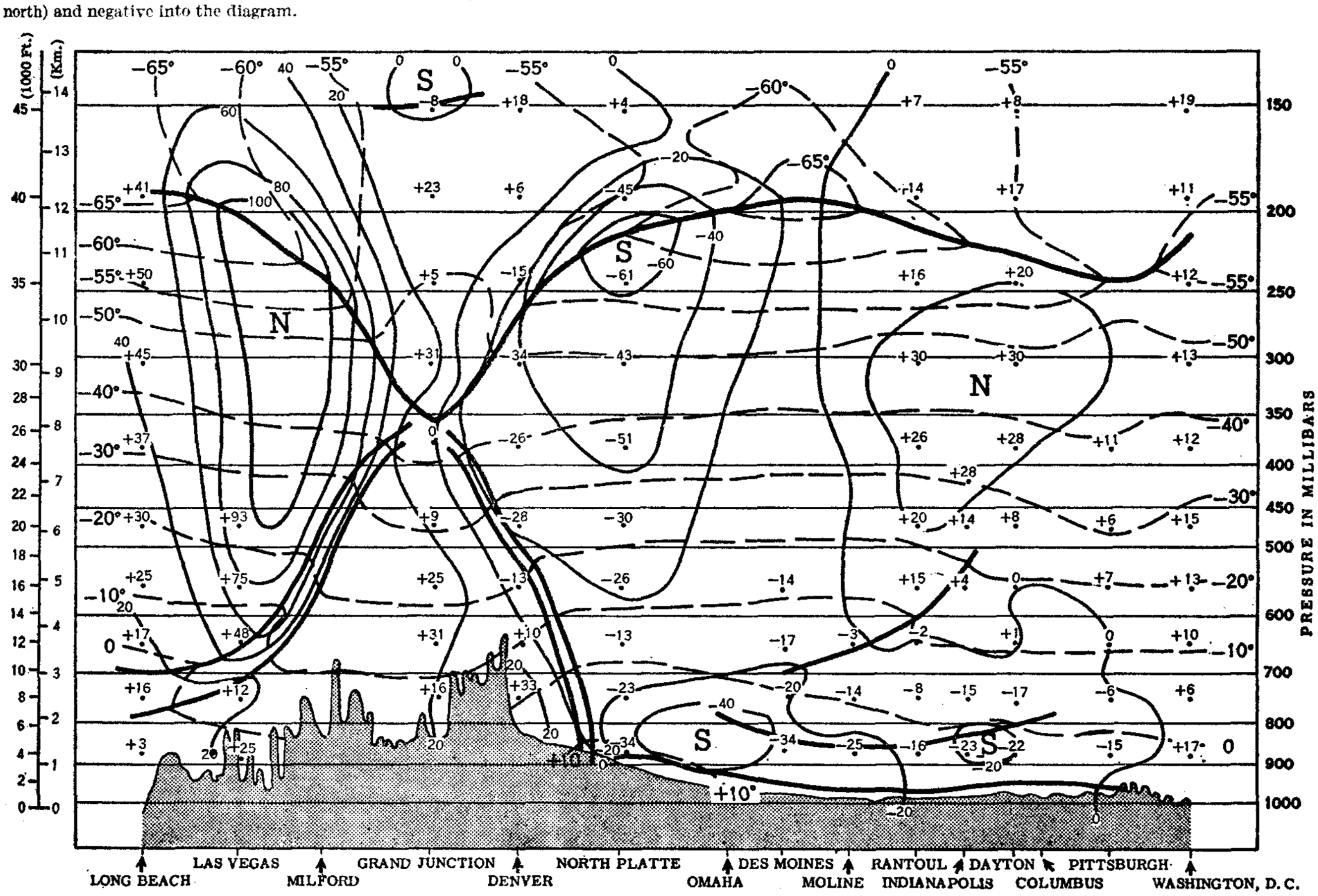

FIGURE 8.—Cross-section at 0300 GMT on February 19, 1954.

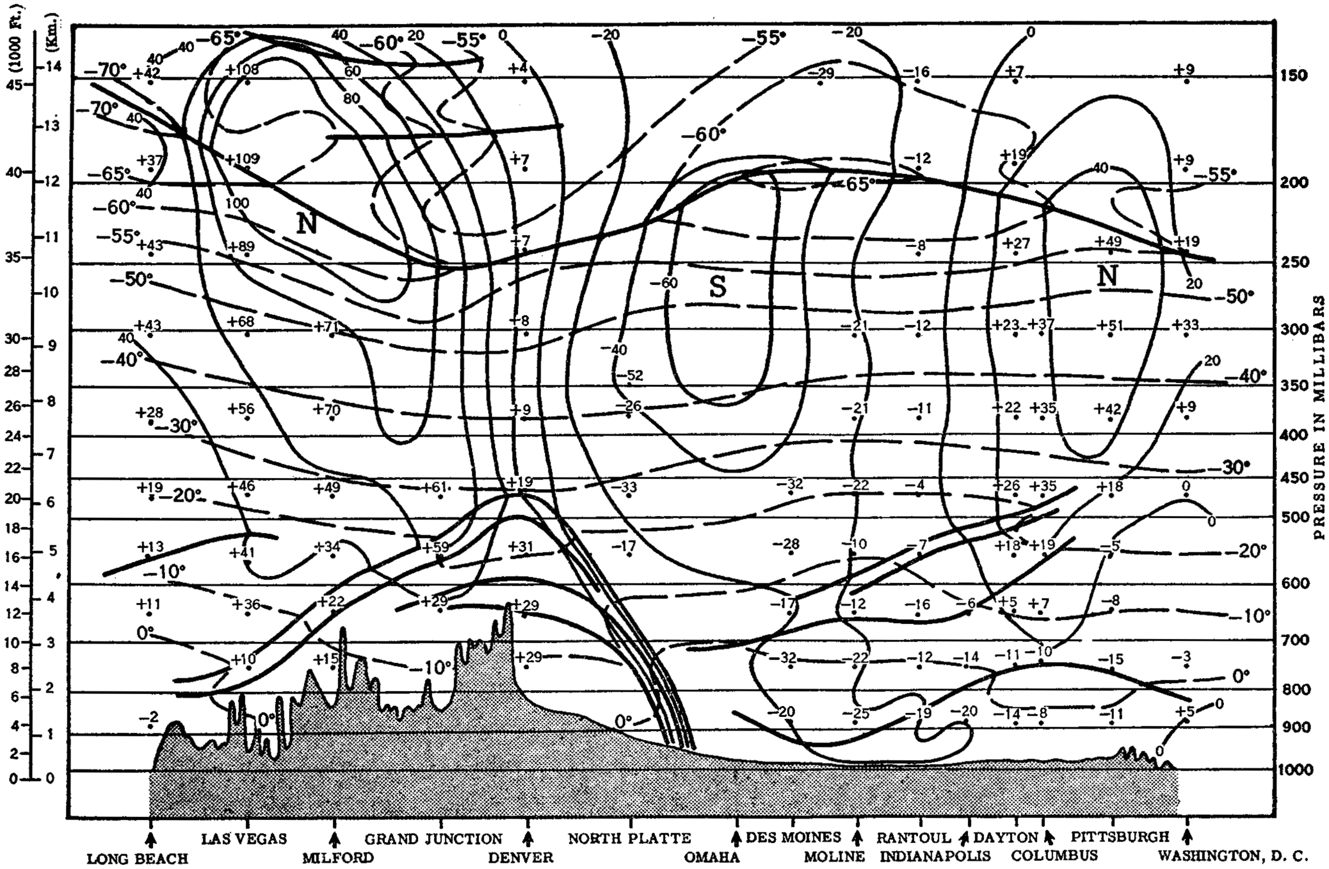

FIGURE 9.—Cross-section at 1500 GMT on February 19, 1954.

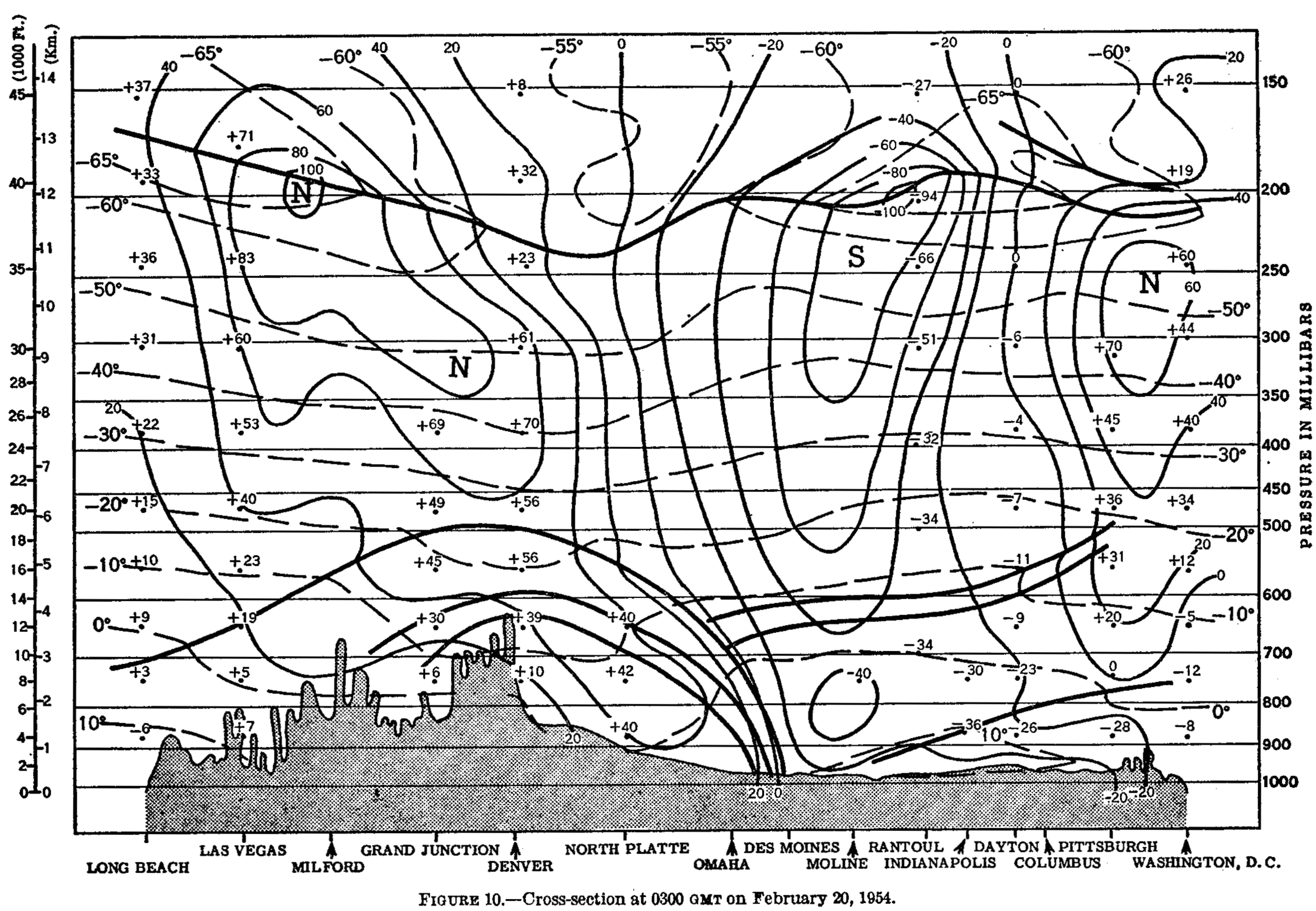

FIGURE 10.—Cross-section at 0300 GMT on February 20, 1954.

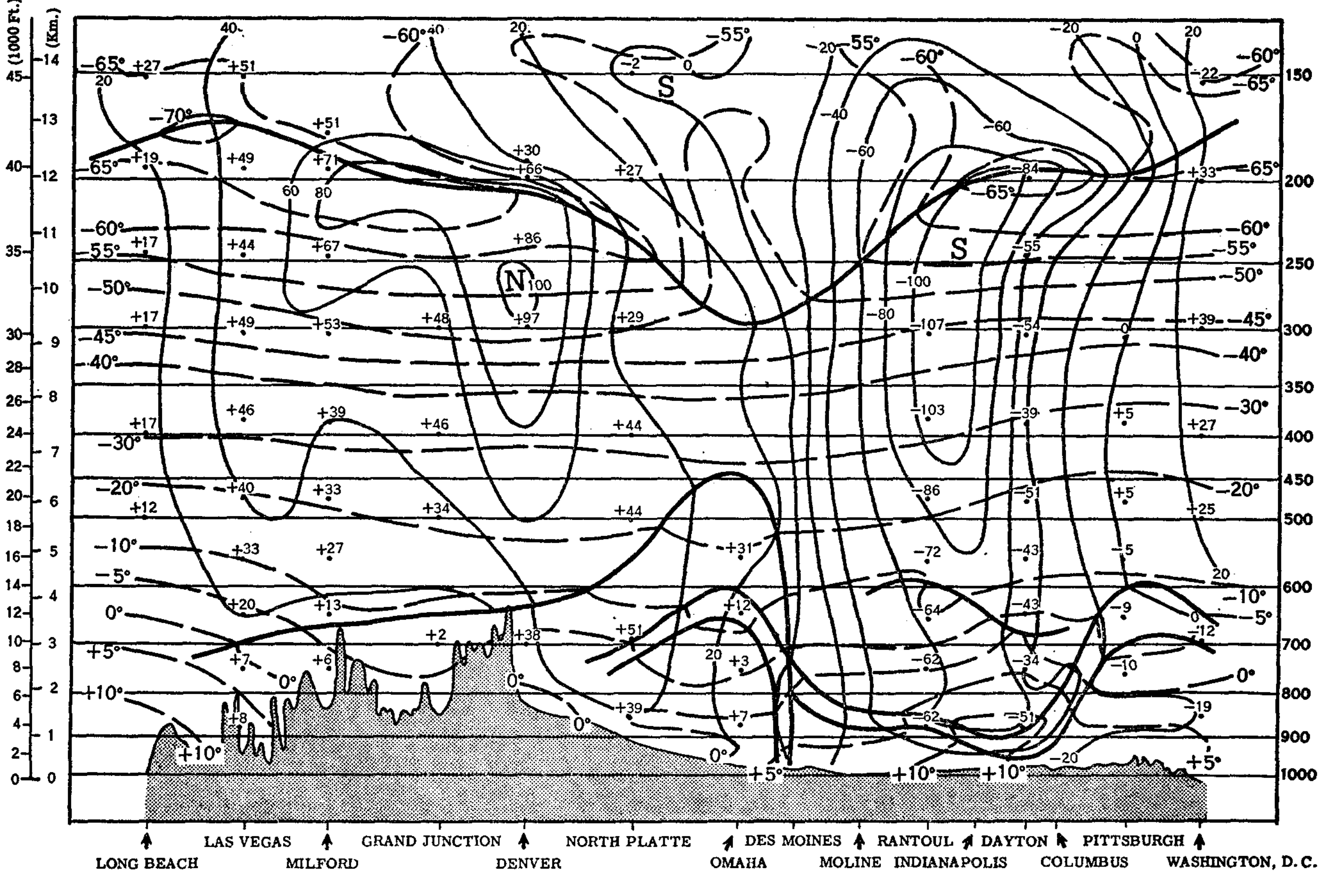

FIGURE 11.—Cross-section at 1500 GMT on February 20, 1954.

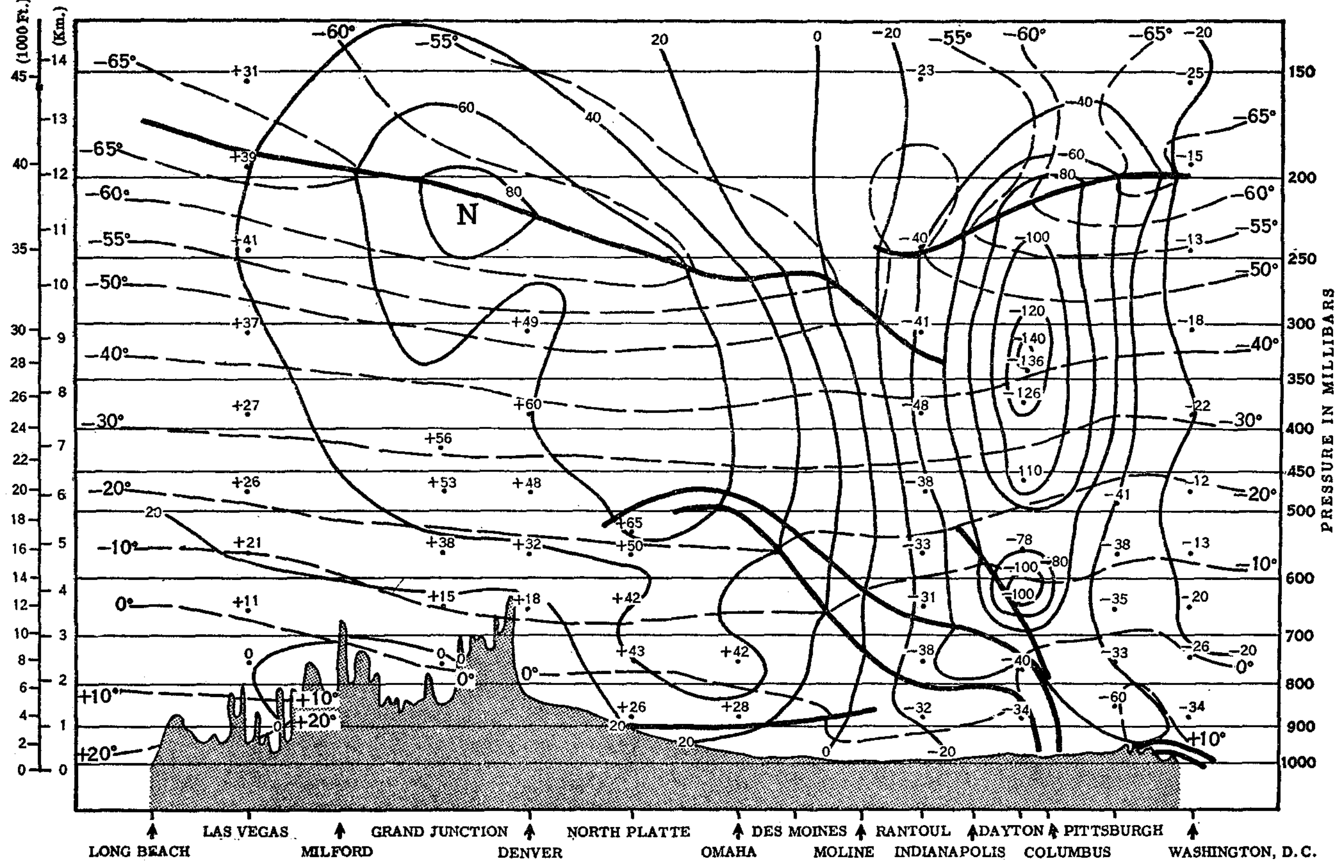

FIGURE 12.—Cross-section at 0300 GMT on February 21, 1954.

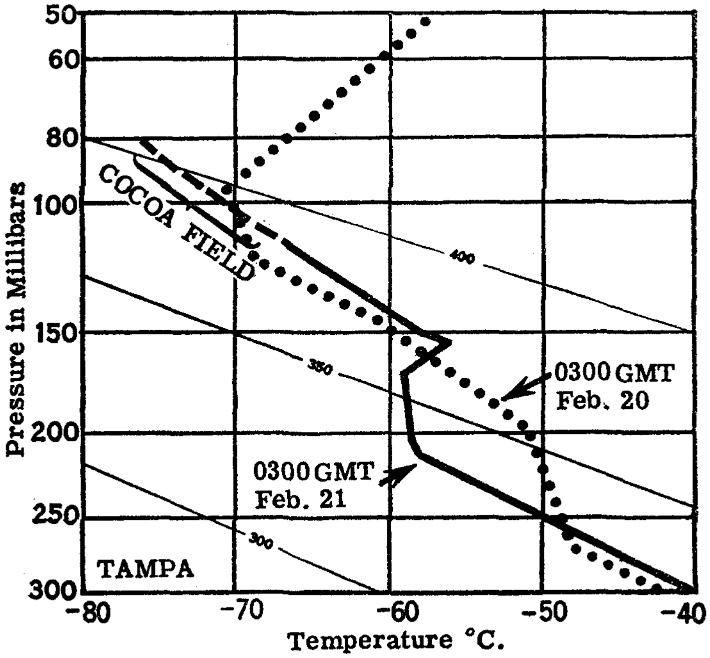

FIGURE 13.—Radiosonde data over Tampa, Fla. at 0300 GMT on February 20 and 21.

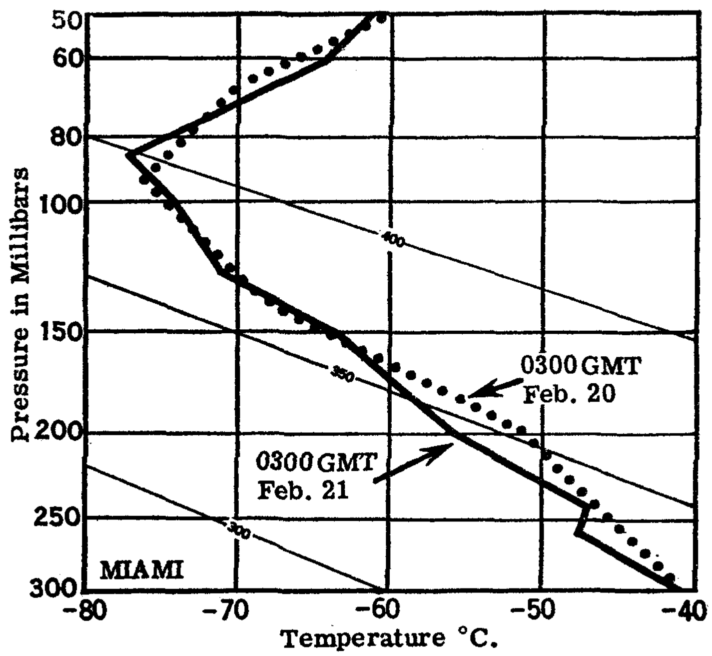

FIGURE 14.—Radiosonde data over Miami, Fla. at 0300 GMT on February 20 and 21.

mediate contours brings the computed winds nearer to, *but still not equal to, the speeds of the observed winds.*

One of the outstanding features of this jet was its abrupt appearance on the 200-mb. chart. At 300 mb. and below there was no indication whatsoever of a jet over southern Florida. At 150 mb. the maximum wind was over Miami. This was simply a reflection of the 200-mb. jet. Whether or not it extended to 150 mb. and/or above must remain a matter for speculation due to the sparseness of data. Yet some inferences may be made from the cross-section

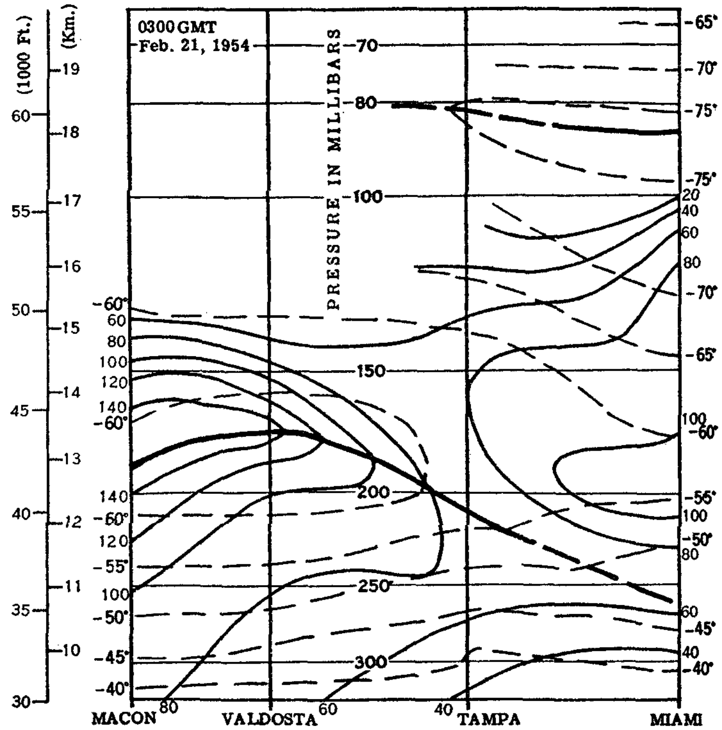

FIGURE 15.—Cross-section over Florida and Georgia at 0300 GMT, February 21, showing tropical and polar type tropopauses.

analyses, which will be discussed in the following paragraphs.

In the search for a logical explanation of this jet several cross-sections through Florida and Georgia were analyzed. These cross-sections (of which one is included (fig. 15)) and radiosondes for Tampa and Miami (figs. 13 and 14) clearly show two tropopauses over the Florida peninsula. Tampa (fig. 13) at 0300 GMT, February 20 exhibited a strong tropopause at 100 mb. and a potential temperature of 393° A. Also, at 270 mb. there were indications of a very weak tropopause with a potential temperature of 328° A. Twenty-four hours later this tropopause had sharpened markedly and was found at 210 mb. with a potential temperature of 336° A. The higher tropopause was not reached by the sounding but is believed to have been near the terminal point of the radiosonde taken at Cocoa, Fla., 82 mb. with potential temperature 405° A. Miami (fig. 14) at 0300 GMT, February 20, showed a strong tropopause at 95 mb. and potential temperature 390° A. Twenty-four hours later this tropopause was at 85 mb. with a potential temperature of 397° A. The first indication of a lower tropopause over Miami was at 0300 GMT, February 21. As can be seen, this indication was indeed very weak.

As shown in the cross-section of figure 15 the lower polar type tropopause was very distinct over all stations except Miami, where it was poorly if at all discernible. However, Miami did exhibit an excellent tropical type tropopause at 85 mb. (see fig. 14). In figure 15 the stations lie roughly along a north-south line, and since the winds were westerly the isotachs are drawn for the observed winds, westerlies blowing into the diagram. From thermal wind considerations the winds should increase with height over the stations where there is a horizontal temperature gradient with cold air to the left of the observed winds. Above Macon, Ga. the winds steadily increased with elevation to a maximum of 158 knots just below the tropopause. Above the tropopause the temperature gradient reversed and correspondingly the winds decreased rapidly with height. Over Tampa and Miami the strongest winds were located just above the polar tropopause, which, as previously pointed out, was extremely weak over Miami but marked over Tampa. The association of this jet on the 200-mb. chart with the tropical tropopause at a much higher elevation seems likely at a more southerly latitude.

It can be shown that the northward bulge of this wind maximum was due to the particular temperature distribution along the tropopauses. As shown in figure 15 at 200 mb., just above the polar tropopause, over Tampa and Miami there was considerably colder air to the left of the observed winds. This was roughly the region where the bulge in the wind maximum occurred. Over Tampa between 200 and 150 mb. the horizontal temperature gradient was very flat and the maximum maintained itself. Over Miami the horizontal temperature gradient reversed near 180 mb. and the winds decreased with elevation. However, only above about the 115-mb. level did the winds begin to fall off very rapidly with height. The reason for this lag in wind decrease from 180 to 115 mb. is difficult to explain, particularly in the absence of data south of Miami. But, it does appear from this cross-section that there was another jet core along the high tropical tropopause to the south of Miami. Moreover, it seems that the axis of this core would have been oriented from the north at lower elevations to the south at higher elevations. Such a configuration would have been in agreement with the temperature field imposed by a high cold tropical tropopause.

TROPOPAUSE

The analysis of this series of cross-sections (figs. 7–12) presented a good opportunity to study the fluctuations of the tropopause as the surface Low and the polar air behind it moved across the country. As the polar tropopause was the predominant one over the cross-section throughout this series, we shall center the discussion around it. In studying the cross-sections it was found that the potential temperature of the tropopause did not vary more than a few degrees as long as there were no large fluctuations of the tropopause. When the cold dome of the polar air mass became quite deep and the tropopause lowered above this dome, the potential temperature of the tropopause decreased as much as 25° C.

At 1500 GMT, February 18 (fig. 7) the tropopause west of Rantoul, Ill. was close to 200 mb. except over

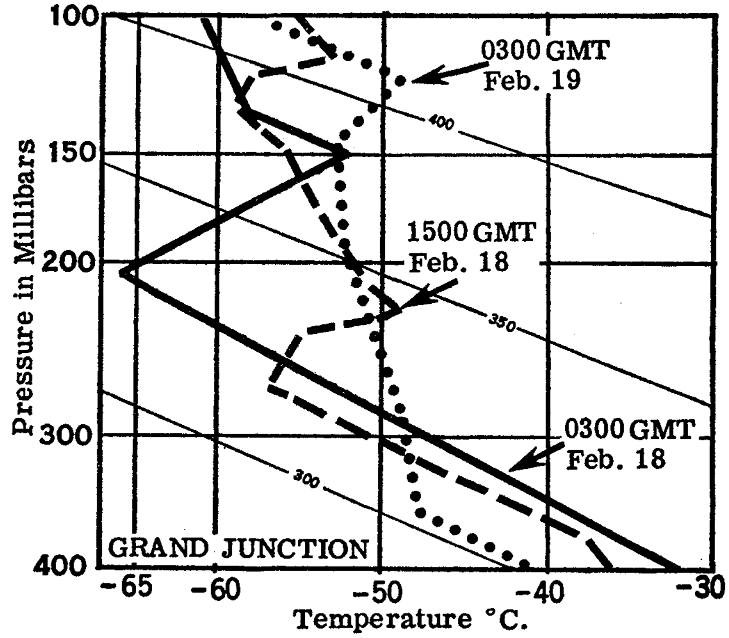

FIGURE 16.—Radiosonde data from Grand Junction, Colo. at 0300 and 1500 GMT on February 18 and 0300 GMT on February 19, 1954.

Grand Junction, Colo. where it was much lower. Twelve hours previous (see fig. 16) it had been near 200 mb. at that station also, but had begun to lower by this time. Cooling had already begun above the 750-mb. level, as can be noted by the depression in the isotherms in figure 7 at Grand Junction.

At 0300 GMT, February 19 (fig. 8), 12 hours later, the cold dome had moved eastward and was centered near Grand Junction. The cooling at that station extended to 320 mb., which was the greatest height along this cross-section in the series to which the cold air penetrated. The front at this height was weak and indistinct, but the tropopause was quite sharp, having lowered to the 350-mb. level. Figure 16 shows the lowering of the tropopause at Grand Junction as the cold air moved over the station. In this case the potential temperature dropped from 325° A. at 0300 GMT, February 18 to 303° A. 24 hours later. There was no concrete evidence of any break in the tropopause, only the rapid lowering of this surface. After this time the cold dome at the surface flattened out, with the top of it reaching about 470 mb. at Denver at 1500 GMT, February 19. Figure 9 shows this flattening, and with it the raising of the tropopause above it. The potential temperature of the tropopause still had a range of 25° C. from Long Beach to Grand Junction, but over the eastern half of the cross-section the potential temperature was within 5° C. of 330° A. A secondary cold front appeared for the first time on this cross-section, and slowly became the more pronounced of the two fronts. The isotherms in figure 12 bear this out, and show that the first front had almost completely frontolized by this time.

The warm front which moved northward across the Eastern States in this series was first discernible on the cross-sections in figure 9, appearing from Des Moines, Iowa to Columbus, Ohio.

The depression in the tropopause above the subsiding cold air mass was still becoming less pronounced at 0300 GMT, February 20 (fig. 10) and the potential temperature range along the tropopause had decreased to 13° C. The warm front over the Eastern States had joined with the cold front as it moved northward, and had begun to lower as seen in figure 10.

At 1500 GMT, February 20 (fig. 11) the western portion of the cold air had continued to subside, with the weakening frontal surface located near 650 mb. to the west of Denver. With this subsidence in the west, a deepening of the cold air and a lowering of the tropopause took place at Omaha, Nebr. A study of the plotted adiabatic chart for Omaha at this time also gave no indication of a break in the tropopause—only a lowering from 200 mb. at 0300 GMT, February 20 to 300 mb. at 1500 GMT, and then back to 250 mb. 12 hours later. The odd appearance of the warm front in figure 11 is mainly due to the orientation of the cross-section with respect to the warm front. The front was roughly parallel to and just south of the cross-section from Illinois to southeastern Ohio, where it turned southward to the Atlanta, Ga. area and then northeastward to Norfolk, Va.; that is, the front was retarded in its northward movement by the Appalachians. By 0300 GMT, February 21 (fig. 12) the warm front had almost moved off the cross-section, with only Washington, D. C. remaining in the cold air (see fig. 3).

The only tropopause break in the series was found over Rantoul, Ill. at 0300 GMT, February 21 where the upper air sounding indicated a double break in the lapse rate. In itself, this sounding was not a clear-cut case, but the ones taken 12 hours later at Rantoul and Dayton, Ohio did indicate an overlapping of the tropopause.

When analyzing tropopause charts, quite often there is a tendency to draw too many break-lines*, where two tropopauses overlap each other. In figure 8 the tropopause had a steep slope on each side of Grand Junction, where the cold dome was centered, and a potential temperature decrease of about 30° C. from Long Beach to Grand Junction. This was a lowering in the tropopause of 12,000 feet in 24 hours at Grand Junction, and presented a temptation to encircle the latter station with a break-line. It is the opinion of the authors and others after careful study of the plotted adiabatic charts, that there was no break in the tropopause, but only the steep slope as pictured. Figure 11 shows this same dip in the tropopause, but to a lesser degree. This phenomenon can evidently be expected over deep cold domes. Careful study should be given to individual raobs, the polar front, and the high level isotach analyses before break-lines are entered on a tropopause analysis.

*For an explanation of "break-lines" the reader is referred to [4].

SUMMARY

As the storm moved across the country the incoming or northwesterly core of the jet stream slowly weakened from about 140 knots to about 70 knots and lowered from 200 mb. in figure 7 to about 350 mb. in figure 12. The new jet core which appeared at 175 mb. over Las Vegas, Nev. in figure 9 also lowered and weakened slowly during the series. After the surface Low became organized, the returning southerly core of the jet also lowered in height from 230 mb. in figure 8 to about 320 mb. in figure 12. The increase of the southerly wind speed normal to the cross-section was approximately equal to the decrease of the northerly wind speed during the series; i. e., from about 70 to 140 knots. This shows the jet maximum moving along the jet stream and around the upper air trough.

The smallest variation in space of the height of the polar tropopause was 8,000 feet at 0300 GMT, February 20 (fig. 10) when it was at 43,000 feet over Long Beach, Calif. and 35,000 feet over North Platte, Nebr. The greatest variation occurred in association with the deep cold dome 24 hours earlier (fig. 8) when the tropopause had lowered to 40,000 feet at Long Beach and to 26,000 feet at Grand Junction, a variation of 14,000 feet.

While the jet stream, tropopause, and general synoptic conditions may at times appear to be at wide variance with generally accepted models, a careful analysis of the data in this study leads to the conclusion that the current popular models [2, 3] suffice very nicely to explain situations that may at first glance appear to be inconsistent. This is not to imply that all present ideas are in agreement or that all or any one may be taken as the ultimate answer. Undoubtedly, as the science of meteorology progresses, refinements and revisions will be incorporated into the various models, and at times some models will best fit one type of situation, while at other times another model will be more applicable.

ACKNOWLEDGMENTS

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